



**AFRL-RQ-WP-TR-2014-0043**

# **EVALUATION OF NEXT GENERATION THERMAL STABILITY-IMPROVING ADDITIVES FOR JP-8**

## **Phase II – Specification, Materials, Filtration, and Fit-For-Purpose Evaluations**

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**DECEMBER 2013  
Interim Report**

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## FOREWORD

In the mid-1990s the U.S. Air Force and the Air National Guard began using JP-8 containing a thermal stability-improving additive, Spec-Aid 8Q462, in truck-refueled aircraft. Manufactured by GE Betz (formerly Betz Chemical and Betz Dearborn), this additive was selected from hundreds of additives tested during a 5-year evaluation period by AFRL/PRTG (now AFRL/RQTF) and The University of Dayton Research Institute (UDRI). Fuel containing this additive was designated JP-8+100 – signifying the improvement in fuel thermal stability by up to 100 °F.

After nearly a decade of this additive being used in the field, the Defense Energy Support Center (DESC) sought assistance from the Fuels Branch (now Fuels and Energy Branch) at AFRL to develop and evaluate a next generation thermal stability-improving additive that could be fielded as a drop-in alternative to the currently used Spec-Aid 8Q462 used in JP-8+100. In response to the DESC request, AFRL proposed a multi-phase program to develop, evaluate and approve one or more additives meeting the goals of the program. In Phase I, additive manufacturers were solicited for candidates for evaluation. Candidate additives were screened for their impact on fuel thermal stability using an array of bench and rig-scale test devices. Those candidate additives that were found to provide thermal stability-enhancing performance equivalent to or better than the existing Spec-Aid 8Q462 additive were evaluated in a Phase II program where additives would be studied to determine their impact on fuel properties and characteristics. The goal of this broader scope program would be to approve qualifying additives as drop-in alternatives to Spec-Aid 8Q462.

This report recaps the findings in the Phase I Report<sup>1</sup> and describes the results of the Phase II Specification Testing, Fit-For-Purpose testing, Materials Compatibility Evaluations and Filtration Testing. Details of the Phase II testing can be found in the final report issued from Pratt & Whitney (“Evaluation of Next Generation High Heat Sink Fuel Additives,” FR-26662-5). It is available as AFRL Technical Report AFRL-RQ-WP-TR-2012-0267.

While the Pratt & Whitney report documents engine manufacturer approval for use of all the additives evaluated in this study, not all are recommended for actual procurement and fielding based on the balance of data presented in this report. At the conclusion of this report, recommendations are made concerning which additives are recommended for field use.

## ACKNOWLEDGEMENTS

This work was co-funded by AFRL/RQTF (Formerly AFRL/PRTG) and the Defense Energy Support Center (DESC), now Defense Logistics Agency, DLA. This program was unique in that it is one of the first times all of the major aircraft engine original equipment manufacturers (OEMs) cooperated together, shared data and cooperatively reviewed and approved both testing protocols and the resultant data. A special thanks goes to Tedd Biddle and Margaret Adamson of Pratt & Whitney for organizing all of the OEMs for this important work.

The author also wishes to thank:

- 1) Lt. Col. Rob Foster for his support to the program – especially in support of the Navy-run Filtration Study at Patuxent River.
- 2) Milissa Flake for contract management and general cat-herding during the program.
- 3) All of the additive manufacturers for their patience as we worked through this program.

## List of Acronyms and Abbreviations

ACRONYM	DESCRIPTION
5M	Filter Style for Fuels with Military Fuel Additives
5M100	Filter Style for Fuels with Military and Thermal Stability-Improving Additives
AFRL	Air Force Research Laboratory
AO	Antioxidant
ASTM	American Society for Testing and Materials
CI/LI	Corrosion Inhibitor/Lubricity Improver
DESC	Defense Energy Support Center
DLA	Defense Logistics Agency
EI 1581	Specification and Qualification Procedures for Aviation Jet Fuel Filter/Separators
FFP	Fit-For-Purpose
FSII	Fuel System Icing Inhibitor
GE	General Electric
JFTOT	Jet Fuel Thermal Oxidation Tester
mg/L	milligrams per Liter
P&W	Pratt & Whitney Aircraft
pS/m	pico Siemens per meter
QPL	Qualified Products List
RR	Rolls Royce
SET	Single Element Test as defined in EI 1581
SDA	Static Dissipater Additive
SLV	Sleeve-style filter element
SBS	Side-by-side filter element form
SwRI	Southwest Research Institute
UDRI	University Of Dayton Research Institute
USAF	United States Air Force
WPAFB	Wright-Patterson Air Force Base



## **1.0 Executive Summary**

### **1.1 Program Background**

In the mid-1990s the U.S. Air Force and the Air National Guard began using JP-8 containing a thermal stability improving additive, Spec-Aid 8Q462, in truck-refueled aircraft. This additive, manufactured by GE Betz (formerly Betz Chemical and Betz Dearborn) was selected from hundreds of additives tested during a 5-year evaluation period by AFRL/PRTG (now AFRL/RQTF) and The University of Dayton Research Institute (UDRI). Fuel containing this additive was designated 'JP-8+100' – signifying the improvement in fuel thermal stability by up to 100 °F.

After nearly a decade in the field, the Defense Energy Support Center (DESC)(now Defense Logistics Agency, DLA) sought assistance from AFRL's Fuels Branch (now Fuels and Energy Branch) at AFRL to develop and evaluate a 'Next Generation' JP-8+100 additive that could be fielded as a drop-in alternative to the currently used Spec-Aid 8Q462. In response to the DESC request, AFRL proposed a multiphase program to develop, evaluate, and approve one or more additives meeting the goals of the program. In Phase I, additive manufacturers would be solicited for candidates for evaluation. Candidate additives would be screened for their impact on fuel thermal stability using an array of bench and rig-scale test devices. If any of the candidate additives were found to provide thermal stability-enhancing performance equivalent to or better than the existing Spec-Aid 8Q462 additive, a Phase II program would be initiated to perform a broader-scoped evaluation of the additive to determine the additive's impact on fuel properties and characteristics. The goal of this broader scope program would be to approve qualifying additives as drop-in alternatives to Spec-Aid 8Q462.

After the Phase I program had been initiated and many of the candidate additives initially submitted had been reviewed, AFRL was approached by BASF with another potential candidate additive. Data presented by BASF indicated that this additive could be a valid candidate. Since funding levels and program schedules were already in place, the BASF additive could not be evaluated as a regular part of Phase I. Therefore, BASF contracted directly to UDRI to perform evaluations using the AFRL evaluation protocol in an attempt to catch up with the other candidates. AFRL and DESC agreed that if BASF could demonstrate the additive's effectiveness in the established protocols, then the additive would be considered for inclusion into Phase II evaluation. BASF and UDRI completed thermal stability evaluations and UDRI completed a report that concluded that the BASF additive had thermal stability-improving characteristics equivalent to Spec-Aid 8Q462<sup>2</sup>. With concurrence from DESC, Phase I concluded with the inclusion of the BASF additive.

### **1.2 Phase I Results**

In Phase I of this overall program, the following four additives were down-selected from several candidate additives as having thermal stability-improving performance equivalent to or better than the existing and approved Spec-Aid 8Q462 additive. These additives were:

- 1) BP/Lubrizol OS 169558F, designated in this study as additive **P39**
- 2) Nalco VX-7603, designated in this study as additive **P44**
- 3) Infineum/ExxonMobil NB31011-33 (as of the publication of this document, Infineum has adopted the commercial designation of 'AV100'), designated in this study as additive **P47**
- 4) BASF Kerocom 69781, designated in this study as additive **P50**. As of the publication of this document, BASF has adopted the commercial designation 'Kerojet® 100'.

These additives along with Spec-Aid 8Q462 (designated in this study as additive **P41**) were recommended for further evaluation in the Phase II Fit-For-Purpose (FFP) and Specification Compliance Testing.

A complete summary of the testing in Phase I of this effort is documented in AFRL Technical Report AFRL-RQ-WP-TR-2013-0069 (Reference 1).

### **1.3 Phase II Results and Conclusions**

Based on the overall testing in both Phase I and II, all additives have been approved for use in military turbine engines (see the appendix). However, based on the performance of these additives on an individual basis in the overall Phase II program, AFRL recommends the following additives for procurement and fielding – in no particular order. Additives not receiving AFRL's recommendation for procurement and fielding were non-recommended due mainly to anomalous or nebulous data relating to filtration and water separation. It is recommended that these additives undergo additional filtration/water separation testing and that the results of the testing in this program be combined with any new data to re-evaluate AFRL's position regarding recommendations for procurement and fielding. Recommended additives are:

- Infineum/ExxonMobil NB31011-33 (as of the publication of this document, Infineum has adopted the commercial designation of 'AV100'), designated as additive **P47**
- BASF Kerocom 69781, designated as additive **P50** (As of the publication of this document, BASF has adopted the commercial designation 'Kerojet® 100').
- GEBetz Spec-Aid 8Q462, designated as additive **P41**.

## 2.0 Background

In addition to providing the propulsion energy for flight, military turbine engine aviation fuel (JP-8, MIL-DTL-83133F) is also used as the primary heat sink in current and advanced military aircraft to provide necessary cooling of critical systems. The heat that is added to the fuel by these various cooling processes can cause bulk fuel temperatures to become significantly elevated – often in excess of 300-325°F in some areas of the fuel system. In addition, this same fuel can be exposed to fuel wetted-wall surface temperatures in excess of 500 °F. When any hydrocarbon-based fuel is exposed to these kinds of temperatures, thermal oxidation begins to take place as the oxygen which is dissolved in the fuel begins to react with fuel components.<sup>3</sup>

These thermal oxidation reactions lead to the formation of gums, varnishes and hard carbon deposits in various parts of the fuel system and are commonly referred to as coke or fouling. Depending upon the temperature regime to which the fuel is exposed, the fuel can exhibit different deposition characteristics. In the 550 °F and below range, deposition is mainly characterized as oxidative—where deposition is formed through a series of reactions involving free-radicals, peroxides and oxygen dissolved in the fuel. At temperatures of 900 °F and higher, deposition is characterized as pyrolytic—where the fundamental reactions involve the breaking of molecular hydrocarbon chains instead of undergoing the reactions characteristic of oxidative deposition (See Figure 1). Regardless of the temperature range and method of formation, these deposits represent a significant detriment to the performance of aircraft engines and flight systems. Aircraft engine and airframe maintainers are forced to perform periodic maintenance actions on many fuel system and engine hot section components as a result of this coke.

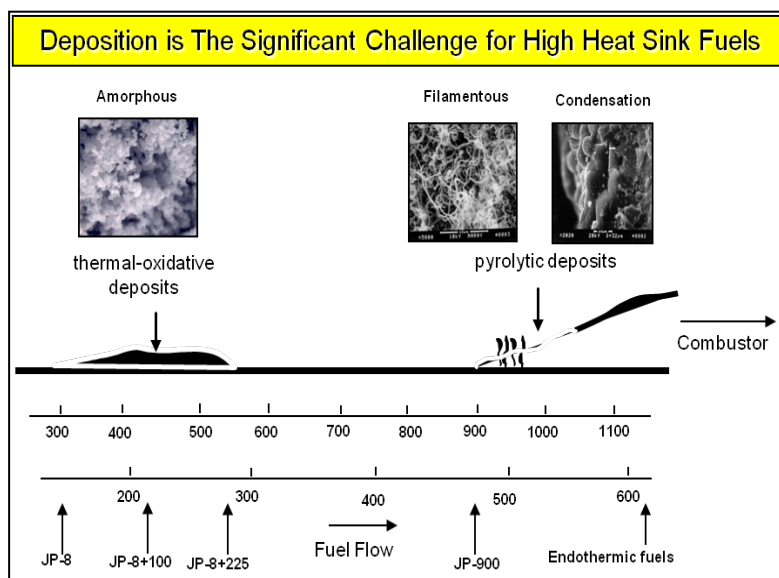
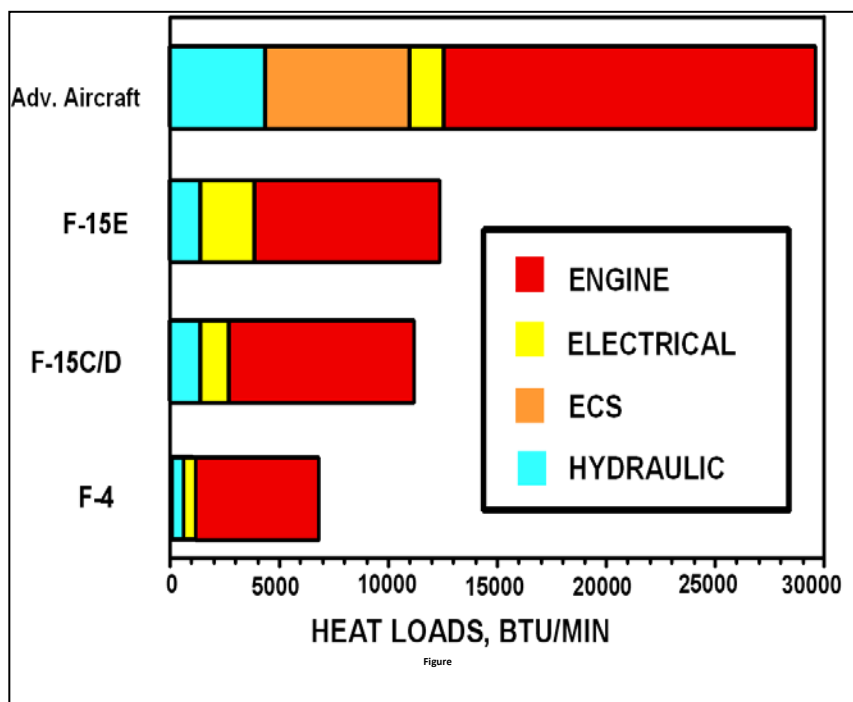


Figure 1 - Deposition Types and Temperature Regimes

Coke present in an aircraft system, particularly the engine, lowers the on-wing time of engines and can result in significant damage to engine hot section components. Even with proper scheduled maintenance, the presence of coke in any part of the aircraft or engine system has a deleterious effect upon performance, reliability, maintainability and longevity. Ultimately, the net result of coking and the effort required to remove it from aircraft systems is increased maintenance costs. Each time an engine is

removed from an aircraft for maintenance, a fixed minimum cost is incurred. Depending on the type of engine involved, the type of maintenance required and the location of coke in the engine, hundreds of thousands of dollars may be expended to return an engine to service.

As current aircraft are updated with new and improved capabilities and as next-generation aircraft are developed and deployed, the cooling requirement which the fuel is expected to supply is rapidly increasing<sup>4</sup> (see Figure 2). Since fuel is used as a coolant medium for aircraft systems, and the amount of cooling available is dependent upon the fuel flow rates within the aircraft system, this problem is compounded by reduction in fuel consumption rates of newer aircraft versus legacy, currently fielded systems. The heat sink or cooling capacity provided by the fuel is directly related to the fuel flow rates through the system. So, at the same time that the heat dissipation requirements are increasing, the reduction of fuel consumption rates means that there is less fuel flowing in the system that can be used to absorb this heat – resulting in higher fuel/fuel system component temperatures. Higher fuel and fuel system component temperatures lead to more coking—and more coking leads to higher fuel system temperatures, reduced thermal management system performance and therefore higher fuel temperatures which leads to ... etc.



**Figure 2 - Aircraft Heat Loads Growth**

In the 1990s, AFRL/PRTG (now AFRL/RQTF) formed a multi-organizational working group representing Government, Academia and Industry to develop a high thermal stability fuel (JP-8+100) with a goal of providing a 100 °F increase in fuel thermal stability and therefore a resultant 50% improvement in the heat sink capability over conventional JP-8. Although hundreds of additives were evaluated during this program, only one additive, GE Betz Spec-Aid 8Q462, was ultimately successful in qualifying for use as a thermal stability enhancing additive<sup>5</sup>. The fuel resulting from the addition of this approved additive at 256 mg/L is designated as JP-8+100. This additized fuel was first fielded in 1994

with the Oregon Air National Guard located at Klamath Falls, Oregon. Since that time, no other additive has been approved for use as a +100 additive.

In the last two decades that the currently approved additive has been in use in the field, Users have developed a contentious relationship with it. While it has been conclusively shown in study after study that there are measurable benefits to using the additive in terms of aircraft/engine maintenance and operation, there has always been a concern that since the GEBetz additive contains a detergent dispersant as a part of the active formulation, this detergent dispersant might decrease the water separation effectiveness of filter coalescers. While there was no technical data to support this concern, neither was there data to refute it. This lack of data has led to fear/skepticism being the driving factor for constraints on logistics related to aircraft defuels and fuel returns to bulk (RTBs). Because of this, some Users have been less than enthusiastic in their embrace of this new additive technology. In the ensuing two decades since the introduction of Spec-Aid 8Q462, this data gap has been closed and it has now been shown that Spec-Aid 8Q462 has no worse an impact on filter coalescer performance when compared to non-additized Jet A than standard JP-8<sup>6</sup>. During the program described in this technical report, RQTF has accomplished preliminary testing on selected additive supplied by several additive manufacturers (OEMs). Some of these candidate additives not only improve thermal stability equivalent to or better than Spec-Aid 8Q462, some even claim improved water separation performance. If these claims can be substantiated, then these new candidate additives may offer substantial potential for offering improved thermal stability performance without some of the logistical penalties of the currently approved additive. Additionally, at a time when there is consideration being given to making Jet A the Air Force standard fuel and then additizing at User location to meet operational and weapon system needs, it will be vitally important that additive negative effects and the additization process be as transparent to User operations as possible. If a +100 additive can be found that does not have the water separation concerns of the current +100 additive, it becomes infinitely more feasible to accomplish additive injection at the Using location without concern that the additive will adversely affect filter/coalescer function and performance.

From a logistical cost perspective, the availability of only one approved +100 additive increases the cost to DoD and decreases the flexibility of fuel logistics and field operations in the field and in deployed areas. The approval of additional additives for use in JP-8+100 should reduce additive procurement costs and increase additive availability. Without an alternate additive or additives to bring competition to the additive market, there is little incentive for a single additive manufacturer to consider an alternate pricing structure. However, if one or more alternate additives can be approved for use, the resulting competition could result in a significant lowering of additive costs – resulting in potentially significant savings.

Ultimately, the suitability of an additive for use in JP-8+100 is based not only on thermal stability improving performance, but also on chemical and functional characteristics as well as compatibility with existing additives and fuel system materials. Fieldability characteristics -- such as water separation, filtration performance, fungibility with existing additives and fuel delivery systems as well as detectability in the field, performance in combustor and nozzle tests, and altitude relight characteristics are critical elements that determine an additive's ultimate acceptability. Such an evaluation requires a program far more substantial in scope and cost than a single phase program. Therefore, the evaluation and study of these latter characteristics was delegated to a Phase II follow-on to the original Phase I program.<sup>1</sup>

Whereas the bulk of the work in the Phase I thermal stability evaluations was accomplished at AFRL, the nature of the testing for Phase II was out of the range of capability for AFRL. It was recognized that in order for Phase II to be successful, full collaboration and cooperation with engine OEMs would be required. Therefore, a program was initiated with Pratt & Whitney Aircraft, Hartford Connecticut, under Air Force Delivery Order Contract No. F33615-03-D-2354-0015 to “determine suitability and subsequent approval or rejection of up to three candidate thermal stability improving additives and/or a Fischer Tropsch synthetic fuel blend for use in military and commercial aircraft.” This statement was later updated to include a fourth candidate additive evaluation. To accomplish this goal, P&W proposed a program of seven tasks.

**Task 1** was simply a task to facilitate the cooperation and collaboration of the additive and engine OEMs for the program. Multi-party non-disclosure agreements (NDA) were signed and executed for each additive and engine OEM. P&W, General Electric (GE), Rolls-Royce (RR), and Honeywell participated as a team focusing on designing tests and procedures, reviewing data and interpreting results. The work performed by each program participant was coordinated under this task.

**Task 2** involved specification testing on all the additives and fuels used throughout the program. Specification Testing was primarily conducted by Inspectorate Laboratory and this effort was largely coordinated through P&W. FFP testing was also conducted under this task. FFP properties are not legislated by fuel specification but are still important characteristics of the fuel/additive as these affect the operation of aircraft systems more directly. These characteristics include things like Jet Fuel Thermal Oxidation Tester (JFTOT) Breakpoint Temperature, inter-additive compatibility per ASTM D 4054, lubricity, electrical conductivity, solubility, Fuel System Icing Inhibitor (FSII)/water effects and storage stability. With a few exceptions, the bulk of FFP testing was accomplished by Southwest Research Institute (SwRI). Additive-additive compatibility was evaluated by the University of Dayton Research Institute (UDRI) under contract F33615-03-2-2347 with the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base (WPAFB), Ohio.

**Task 3** focused on the evaluation of fuel/additive electrical conductivity impacts on fuel gauging systems. This testing was performed by B.F. Goodrich and involved the assessment of key parameters that can affect fuel gauging systems such as fuel density, speed of sound and dielectric constant.

**Task 4** involved Engine Component-type testing and was performed by Honeywell (and SwRI acting under subcontract to Honeywell). There were several subtasks under this task. The subtasks included Engine Fuel Inlet Filter Testing, Cold Fuel Atomization Testing, Auxiliary Power Unit (APU) Ground and Altitude Starting and APU Endurance Testing.

**Task 5** covered Hot Section Materials Testing and Evaluation. This testing was performed by Pratt & Whitney at their Hartford facility and is often referred to as Hot Gas Path testing. In this testing, a series of ‘pins’ of various metallurgies are directly subjected to a combustor flame fueled by the fuel/additive being evaluated. This task evaluated the results of any fuel/additive/materials and coatings compatibility issues.

**Task 6** was the evaluation of Fuel Nozzle performance using the additives. This testing was accomplished by SwRI. The engine OEMs selected GE CFM56 and PW F135 fuel nozzles as being most representative of fuel nozzle technologies currently in use.

**Task 7** involved Combustor Rig Testing which included Altitude Ignition Tests performed by RR and Full Annular Combustor Testing performed by P&W. The Altitude Ignition Tests were performed in a full annular test rig with air blast-type fuel spray nozzles. Ignition, extinction and blowout performances were determined. The objective of the full annular test at P&W was to assess the impact of additives on combustion emissions. While most other testing in this overall program was done both individually on additives and on additives blended together as a soup, full annular testing was accomplished using the additive soup only. In this testing, data was collected on generation of nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>) and unburned hydrocarbons. Test plan points for the test were based on P&W's Next Generation Production Family engine cycle at the extremes of flight conditions. Data was taken at both simulated idle and sea level take-off conditions.

Additional testing was also accomplished to evaluate filter/coalescer performance with the candidate additives and to determine any impact on combustion emissions.

## **3.0 Discussions of Experimental Results**

### **3.1 Pratt & Whitney Program Tasks and Results**

This section recaps the testing and results from the Pratt & Whitney report AFRL Tech Report AFRL-RQ-WP-TR-2012-0267, “Versatile Affordable Advanced Turbine Engine (VAATE) Phase I: Delivery Order 0015: Evaluation of Next-Generation High-Heat Sink Fuel Additives, Phase II – Additives Qualification, September 2012 (also issued as Pratt & Whitney report “Evaluation of Next Generation High Heat Sin fuel Additives,” FR-26662-5).

#### **3.1.1 Task 1 OEM Teaming Activities**

Task 1 was simply a task to facilitate the cooperation and collaboration of the additive and engine OEMs for the program. Multi-party non-disclosure agreements (NDA) were signed and executed for each additive and engine OEM. P&W, GE, RR, and Honeywell participated as a team focusing on designing tests and procedures, reviewing data and interpreting results. The primary work was performed by P&W, GE, RR, Honeywell, AFRL UDRI, SwRI and Inspectorate Laboratory also performed testing under one or more subcontracts to these primary participants

#### **3.1.2 Task 2 – Impact on Specification and Fit-For-Purpose Testing**

Task 2 involved specification testing on all the additives and fuels used throughout the program. Specification Testing was primarily conducted by Inspectorate Laboratory and this effort was largely coordinated through P&W. Fit-For-Purpose (FFP) testing was also conducted under this task. FFP properties are not legislated by fuel specification but are still important characteristics of the fuel/additive as these affect the operation of aircraft systems more directly. These characteristics include things like JFTOT Breakpoint Temperature, inter-additive compatibility per ASTM D 4054, lubricity, electrical conductivity, solubility, FSII/water effects and storage stability. With a few exceptions, the bulk of FFP testing was accomplished by Southwest Research Institute (SwRI). Materials compatibility was evaluated by the University of Dayton Research Institute (UDRI) under contract F33615-03-2-2347 with the AFRL at Wright-Patterson Air Force Base (WPAFB), Ohio.

##### **3.1.2.1 Specification Testing**

Specification (MIL-DTL-83133) tests were performed by Inspectorate Laboratory on two baseline fuels and 5 additives (including the currently in-use and approved Spec-Aid 8Q462) and an additive soup. Baseline fuels were a typical JP-8 and a reference pseudo-fuel prepared and provided by AFRL designated Jet Reference Fuel Number 3 (JRF-3). Additive testing was accomplished at four times the concentration of 256 mg/L being requested for approval ( $4 \times 256 \text{ mg/L} = 1024 \text{ mg/L}$ ). The final P&W technical report documents that all but one additive (P44) exceeded the maximum allowable limits for existent gums in this testing. The additives that exceeded the limit at 4X were retested at 2X. Those that exceeded the limit at 2X were retested at 1X. All members of the project team including OEMs, AFRL, Navy, UDRI and SwRI agreed that it would not be unusual for the additives to exceed existent gum limits at 4X or 2X due to the additive molecules being much heavier in molecular weight than fuel. Also, high existent gum levels in fuel is typically an indication of contamination of a fuel by higher molecular



weight or higher boiling materials and generally reflects poor handling practices rather than any issue with the fuel itself. Under this consideration, all the additives passed the existent gum test in the baseline JP-8 fuel and all but one (P47) passed in the JRF-3 fuel. In this case P47 exceeded the existent gum limit of 7 mg/100 ml giving results of 7.4 mg/100 ml and 7.8 mg/100 ml. This was not taken as a failure because the results were with the reference fuel and not JP-8.

Several of the additives exceeded particulate contamination limits. These failures were attributed to dirty sample containers or poor handling as particulate contamination has nothing to do with any attribute, physical or chemical, of any additive itself since additives cannot generate dirt.

Electrical conductivity was also evaluated as a part of the specification testing in this task. However, the baseline fuel (JP-8) did not meet the minimum requirement of 150 pS/m for JP-8. At testing levels of 4X concentration, four of the five additives exceeded the upper limit of 700 pS/m. However, the soup of additives tested within specification limits. Program participants suspect anomalous data in the first 4X testing since only one additive exceeded the 700 pS/m limit in the JRF-3 fuel. The soup also exceeded the limit in the JRF-3 fuel. The additives were re-blended into fuel at 4X and tested again. In the retest, only one additive (P41) exceeded the conductivity limit. Since conductivity levels were fairly high for all the additives, each additive was re-blended into JP-8 at 2X concentration and retested. At 2X, most of the additives produced much lower conductivity levels except for P41 which still exceeded the limit. P41 was re-blended at 1X and it passed with a level of 645 pS/m.

Electrical conductivity effects primarily ground refueling static discharge issues. Very high conductivities can affect fuel system gauging systems. For ground safety static discharge issues, high conductivity is of no issue – in fact higher conductivity insures that electrical static charges dissipate rapidly during ground fuels handling functions. So the impact on gauging systems is the primary concern with high conductivities. However, according to Dr. Cyrus Henry of Innospec, an internationally recognized expert in fuel electrical conductivity, it takes a conductivity rating in the neighborhood of 30,000 pS/m to adversely affect fuel gauging systems. Bruce Kline of B.F. Goodrich believes that for 400Hz gauging systems needing conductivities lower than 6,600 pS/m to keep error rates below 1%, this error rate may not be tolerable for some aircraft systems. But in perspective, P41 giving a conductivity rating of 767 at 1X concentration is a long way off of this 6,600 practical ‘limit’. Hence it was the opinion of the partners that electrical conductivity was of no issue for any of the additives.

### **3.1.2.2 Fit For Purpose Testing**

FFP testing was also conducted under Task 2. FFP properties are not legislated by fuel specification but are still important characteristics of the fuel/additive as these affect the operation of aircraft systems more directly. These characteristics include things like JFTOT Breakpoint Temperature, inter-additive compatibility per ASTM D 4054, lubricity, electrical conductivity, solubility, FSII/water effects and storage stability. With a few exceptions, the bulk of FFP testing was accomplished by SwRI. Additive-additive compatibility was evaluated by the UDRI under contract F33615-03-2-2347 with the AFRL at WPAFB, Ohio.

Task 2 testing results (performed by SwRI) are given below along with the conclusions from that testing:

**Jet Fuel Thermal Oxidation Testing (JFTOT)** – All of the additives as well as the soup improved the thermal stability breakpoint of both the JP-8 and the JRF-3 baseline fuels at least to the practical limit that can be measured by the JFTOT. Therefore all additives performed well for thermal stability improvement in the JFTOT – replicating the overall results of the Phase I program.

**Additive-Additive Compatibility** – this testing showed no evidence of additive-additive incompatibilities. However, both by itself and in blends, additive P39 resulted in a significant yellowing of the fuel in which it was blended.

**Lubricity** – neither the individual additives nor the blends had any adverse impact on fuel lubricity.

**Electrical Conductivity Long-term Stability** – testing showed that only two of the additives, P44 and P47, showed less than a 40 percent change over time. This is not anticipated to be a critical issue since application of thermal stability additives almost always occurs at the point of use and not in fuel that will experience long-term storage.

**Fuel System Icing Inhibitor (FSII) Testing** – there were no issues except that additives P39, P41 and P44 promoted precipitation of the FSII/water mixture in various amounts. No additional assessment was made based on this precipitation behavior.

**Storage Stability Testing** – Evaluation of peroxide formation was performed in this testing. Additive P44 stood out as having an adverse effect upon peroxide formation in both the JP-8 and JRF-3 fuels. Since thermal stability-improving additives are typically added to fuel at the point of use, long term storage does not appear to be an issue. However, if this typical use scenario changes significantly, storage stability may need to be revisited.

### **3.1.2.3 Materials Compatibility Testing**

Testing and analyses were performed at AFRL and at UDRI. The purpose of the materials testing was to determine if there was any potential for any one or combination of the additives to degrade materials used in fuel tanks, airframes or engines. A full suite of material compatibility tests were performed by UDRI under AFRL direction. Both metallic and nonmetallic materials were exposed for 28 days to baseline JP-8 without additives and JP-8 containing the candidate additives (including the currently used and approved Spec-Aid 8Q462). No detrimental short term effects were noted. However, some materials did exhibit some limited, nondetrimental degradations. To ensure compatibility, the report recommended that these materials which exhibited some degradation should be monitored field applications even though serious compatibility issues are unlikely to manifest themselves.

Prior to approving the additives for use in their engine systems, all engine OEMs reviewed this materials compatibility data carefully with the ultimate determination that the testing did not indicate any significant potential for incompatibility with materials used in current systems. All engine OEMs have since approved all of these additives for use.

### **3.1.3 Task 3 – Fuel Gauging Study (B.F. Goodrich)**

Task 3 focused on the evaluation of fuel/additive electrical conductivity impacts on fuel gauging systems. This testing was performed by B.F. Goodrich and involved the assessment of key parameters

that can affect fuel gauging systems such as fuel density, speed of sound and dielectric constant. In their final report, B.F. Goodrich concluded that the additives had no measureable impact on density, speed of sound and dielectric constant and therefore should have no discernible impact on fuel gauging systems.

### **3.1.4 Task 4 – Engine Component Testing (Honeywell)**

Task 4 involved Engine Component-type testing and was performed by Honeywell (and SwRI acting under subcontract to Honeywell). There were several subtasks under this task. The subtasks included Engine Fuel Inlet Filter Testing, Cold Fuel Atomization Testing, Auxiliary Power Unit (APU) Ground and Altitude Starting and APU Endurance Testing.

#### **3.1.4.1 Engine Fuel Inlet Filtration Testing**

This testing was conducted by SwRI at the request and under the oversight of Honeywell. In this testing, a small fuel filter used on several turbofan and turboprop engines was tested to evaluate the filtration efficiency and dirt holding capacity at the filter's rated flow using a baseline JP-8 and additized JP-8. To minimize testing cost, the soup of 5 additives was used with a total additive concentration of 1280 mg/L (5 x 256 mg/L). Duplicate tests were run for each fuel and runs were based on a modified version of SAE ARP1827A. The details of this modification are documented in P&Ws Appendix A report<sup>7</sup>.

Testing showed an apparent small increase in filter dirt holding capacity for the additized fuel. The report concludes that this increase may have been due to the dispersant present in the additive(s) keeping the smaller particles from agglomerating. Filtration efficiencies for small particles was lower than for the additized fuels during the initial portion of the test. But, as soon as the filter began to load with dirt, filtration efficiencies returned to nominal JP-8 levels. There was no such change in efficiencies for larger particles and no particles larger than the 40 micron filter rating got past the filter. The testing concluded that observed behavior would have no impact on engine fuel system durability or operability.

#### **3.1.4.2 Cold Fuel Atomizer Bench Testing**

For this testing, performed by Honeywell in their facility in Phoenix, AZ, a soup of additives at a total concentration of 1280 mg/L was used in a baseline JP-8 fuel. A small increase in atomizer check valve restriction was observed, however, with the additized fuel as measured by a minor increase in valve opening pressure. However, valve opening pressures remained within specification tolerances and no significant change in check valve function at ambient conditions. Results of check valve and atomizer spray testing in JP-8 will not adversely impact ambient, cold or altitude starting of Honeywell engines and APUs.

#### **3.1.4.3 APU Ground and Altitude Starting**

APU testing was accomplished by Honeywell at the Honeywell Aerospace site in Phoenix, AZ using a Honeywell G250 APGS. This APU is typical of the type used in fight (and some bomber) aircraft. Testing was accomplished using a soup of additives at a total concentration of 1280 mg/L in JP-8. The additized fuel successfully completed ground start and operational tests as well as cold and altitude start tests with no adverse effect upon APU performance, operability or durability concluding that the additives

will have no impact in field use on cold or altitude starting “for all Honeywell APUs in the USAF inventory.”

#### **3.1.4.4 APU Endurance Testing**

APU endurance testing was accomplished using a 131-9 APU in a 150-hour test using a soup of additives with a total concentration of 1280 mg/L in JP-8. Testing concluded that APU performance was within normal operating limits and was similar to performance of just a straight unadditized JP-8. Post-test inspections of hot section components as well as functional checks of the fuel control and fuel atomizer revealed that the soup did not impact hardware integrity. On this basis, the report concluded that there were no adverse effects of the additives on engine performance or durability.

### **3.1.5 Task 5 – Hot Gas Path Testing**

Task 5 covered Hot Section Materials Testing and Evaluation. This testing was performed by Pratt & Whitney at their Hartford facility and is often referred to as Hot Gas Path testing. In this testing, a series of ‘pins’ of various metallurgies are directly subjected to a combustor flame fueled by the fuel/additive being evaluated. This is used to verify the compatibility of the combusted additives with common engine hot section materials and coatings – primarily for turbine blades and vanes. For this testing, each additive was blended into fuel at 4X concentration. A soup was not used. Each additive was evaluated independently.

Two evaluations were performed – a 1850 °F cyclic oxidation test using six different alloy/coating combination and a 1600 °F isothermal hot corrosion test using 3.5 ppm salt using seven different alloy/coating combinations. Test samples for both test styles were compared visually and microscopically for effects of the additives. Mass and dimensional changes were also compared before and after testing. In all cases, no significant differences were found. In the Hot Gas Path Testing for the P50 additive, it was noted that the P50 additive/Jet A blend “appeared to significantly reduce surface corrosion” in two of the material alloys tested.<sup>8</sup>

### **3.1.6 Task 6 – Fuel Nozzle Testing**

Task 6 was the evaluation of Fuel Nozzle performance using the additives. This testing was accomplished by SwRI. The engine OEMs selected GE CFM-56 and PW F-135 fuel nozzles as being most representative of fuel nozzle technologies currently in use. Both nozzles were evaluated concurrently. The nozzles were submersed in separate fluidized sand baths and instrumented for control and data acquisition. For this test, each additive was evaluated independently as well as a soup of all five additives (with a total concentration of 1280 mg/L) in JP-8 in order to evaluate any synergistic or antagonistic effects. Testing showed that each of the additives reduced fuel nozzle fouling when compared to a baseline JP-8 fuel.

The F-135 nozzles ran for 50 hours using a two-step flow profile where fuel flow rates were either 62 lb/hr or 250 lb/hr. Two skin temperatures, fuel inlet temperature, fuel outlet temperature and nozzle pressure drop were measured. The target inlet fuel temperature was 365 °F with a fluidized bed temperature of 837 °F. Every 10 hours during the 50-hour test, hysteresis measurements were made.

The CFM-56 nozzle was operated at steady flow conditions at a fuel flow rate of 15 lb/hr with a nozzle skin temperature of 530 °F. Initially, the fuel inlet target conditions were 365 °F, 380 °F, and 395 °F. However, when the P41 additive was tested, no fouling was observed so the target fuel inlet temperatures were increased to 420 °F, 435 °F, and 450 °F. Fouling was observed at these temperatures so these conditions were used for all additives.

For the F-135 nozzle, performance for all 5 additives was similar. Hysteresis results for all additives were well within tolerance for the test. However, the baseline fuel caused complete nozzle failure in just over 20 hours. This attests to the thermal stability-improving nature of the candidate additives.

For the CFM-56 nozzle, the fouling rate for all additives was linear and fell between 0.03 and 0.01 lb/hr-psi<sup>5</sup>. P39 and P41 additive gave fouling rates of between 0.005 and 0.01 lb/hr-psi<sup>5</sup>. The P44 additive exhibited fouling but at an order of magnitude less than the P39 and P41 additives. Additives P47 and P50 exhibited zero fouling.

### **3.1.7 Task 7 – Combustor Rig Testing - Altitude Ignition and Full Annular Testing**

Task 7 involved Combustor Rig Testing which included Altitude Ignition Tests performed by RR and Full Annular Combustor Testing performed by P&W. The Altitude Ignition Tests were performed in a full annular test rig with air-blast-type fuel spray nozzles using an AVTUR fuel. Ignition, extinction and blowout performances were determined. The objective of the full annular test at P&W was to assess the impact of additives on combustion emissions. While most other testing in this overall program was done both individually on additives and on additives blended together as a ‘soup’, testing for this task was accomplished using a soup of additives at 1,280 mg/L total concentration in either JP-8 (for the full annular test) or in AVTUR (for the Altitude Ignition tests done at RR). In Full Annular testing, data was collected on generation of nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>) and unburned hydrocarbons. Test plan points for the test were based on P&W’s Next Generation Production Family engine cycle at the extremes of flight conditions. Data was taken at both simulated idle and sea level take-off conditions.

For the Altitude Ignition testing, RR determined that the addition of the additives resulted in a fuel which continued to meet expectations of an AVTUR fuel. For the Full Annular testing, P&W noted no differences in performance between the baseline fuel and additized fuel. No change in combustion efficiency over a wide range of fuel-to-air ratios was noted. Emissions levels for all emissions species for both baseline fuel and additized fuel were nearly identical. Smoke number of the two fuels was unchanged as well. The report concluded that there were “no indicators from emissions measurements or combustor thermal patterns that a difference in exit temperature distribution exists” between additized and neat baseline fuels.

### **3.1.8 Conclusions From the P&W Overall Report**

**“The results of the testing performed under this program indicate that the additives should have no negative impact on engine or airplane safety, performance or durability. The work conducted under this program supports the position that all four of the candidate additives are fit for purpose for use in commercial and military engines as fuel thermal stability improvers.”**

## 3.2 Navy Filtration Program

To evaluate the filter/coalescer performance of the new candidate additives, a program was initiated by DESC and AFRL with the Naval Fuels and Lubricants Cross Functional Team at Patuxent River (Pax River). The Service Engineer Lead for the program was John J. (Jack) Buffin and the Fuel Filtration and Handling Engineer was Christopher J. Laing. The results of this work were published in a separate publication<sup>9</sup>. Testing in the program included the four new candidate additives approved for inclusion into Phase II from the Phase I effort as well as the currently approved thermal stability-improving additive. Testing was conducted in accordance with the Energy Institute API/EI 1581 (formerly API 1581) Single Element Test (SET) Specification which measures filtration element performance. For this testing, each of the candidate thermal stability-improving additives, as well as the currently approved additive, were added individually to a JP-8 fuel (actually, a Jet A fuel with the standard military package of additives – Fuel System Icing Inhibitor (FSII), Corrosion Inhibitor/Lubricity Improver (CI/LI) and Static Dissipater Additive (SDA)) at a concentration of 256 mg/L and tested using a selection of filter elements most commonly used by the Air Force, Army and Navy. In addition to individual additive tests, a soup of the best performing additives was created by combining equal amounts of these additives to form a ‘soup’. This ‘soup’ of additives was then used to blend into JP-8 at 256 mg/L and tested using the same selection of filter elements tested with the individual additives. In addition to the additive and soup tests, baseline tests were also performed on the neat Jet A blending stock and the JP-8 formulated from that neat Jet A stock.

The selection of filters used for this evaluation included the following:

1. **5M 420 SBS** – a 4-inch diameter, 20-inch long 5<sup>th</sup> Edition M-series filter in a side-by-side configuration used by the US Navy in a 2 filter/coalescer configuration in one housing along with 1 separator.
2. **5M 420 SLV** – a 4-inch diameter, 20-inch long 5<sup>th</sup> Edition M-series filter in a Sleeve configuration used by the US Army in a 2 filter/coalescer/sleeve configuration in one housing with each filter/coalescer used as a sleeve over the top of the separator.
3. **5M100 420 SLV** – a 4-inch diameter, 20-inch long 5<sup>th</sup> Edition M100 series filter in a sleeve configuration used by the US Army with 2 filter/coalescers per housing used as a sleeve over each of the separators.
4. **5M 620 SBS** – a 6-inch diameter, 20-inch long 5<sup>th</sup> Edition M-series filter in a side-by-side configuration used by the US Air Force and the US Navy (shipboard) in a 1 filter/coalescer configuration in one housing along with 1 separator.
5. **5M100 620 SBS** – a 6-inch diameter, 20-inch long 5<sup>th</sup> Edition M100-series filter in a side-by-side configuration used by the US Air Force in a 1 filter/coalescer configuration in one housing along with 1 separator.

### 3.2.1 Baseline Testing

SET testing was conducted in unadditized Jet A and JP-8 formulated from this unadditized Jet A. The JP-8 was formulated by the addition of the standard military package of additives per the then-current publication of the fuel specification MIL-DTL-83133. The military package of additives consisted of Fuel System Icing Inhibitor (FSII), Corrosion Inhibitor/Lubricity Improver (CI/LI) and Static Dissipater

Additive (SDA). All tests were single-pass in which fuel flowed from a holding tank through the system, through a water separation/treatment system and then into a receiving tank.

Jet A baseline testing was accomplished using a 5M 620 SBS and a 5M 420 SBS filter element. Both tests passed EI 1581 criteria. JP-8 was tested with 5M 420 SBS, a 5M 620 SBS and 5M 420 SLV filter elements and passed EI 1581 criteria for all of these elements

### **3.2.2 Individual Additive Evaluations – Additive P39**

Each candidate additive was evaluated in a SET to determine their impact on filter/coalescer performance. In most cases, the testing process was uneventful, regardless of the pass or fail outcome.

However, additive P39 presented some challenges during the testing process. For this particular additive, only one SET was performed. This was due to the unexpected formation of a stable emulsion during the testing.

During the SET, using a 5M100 620 SBS filter, the downstream water concentration in the fuel exceeded 15 ppm during the first low water injection at 35 minutes - hence failing the API/EI 1581 protocol. Due to this early failure, the filter housing and both elements within it were checked to make sure they were installed and functioning properly. Everything was found to be acceptable. So, in order to verify that the filter elements were not the cause of this unexpected early failure, a new set of elements were installed and the test was restarted. This restart test was aborted at 65 minutes during the dirt injection phase for a high filter element differential pressure reading. Once again, the elements and housing were inspected for correct installation and no fault was found. These results were reported to the Air Force and DESC and a joint decision was made to clean up the fuel by removing the additive and thereby restore the fuel to its baseline condition for retesting. In this restoration and removal process, the FSII was to be removed by 'water washing' the fuel by introducing water in a 1-3% water-to-fuel by volume to extract the FSII. The water/fuel solution is then processed through a 600 GPM filter/separator to remove the water/FSII (FSII preferentially dissolves in water rather than fuel). This water/FSII solution is then processed in a wastewater treatment facility to remove remaining hydrocarbon phase from the water phase. However, within 15 minutes of starting the water wash process, the wastewater treatment system overflow alarm was triggered. Investigation revealed that a thick emulsion of fuel and water had formed that could not be separated by the process. The process was stopped and cleaned. The separation process was restarted only this time the flow rate through the system was reduced by 50% to allow the system more time to break the fuel/water emulsion. The washing process was restarted but once again, the treatment system overflow alarm was triggered. Once again, a thick fuel/water emulsion had formed. In hopes that extended settling time would break this emulsion, the system was halted and everything was allowed to sit idle for 48 hours. However, after this time, the fuel in the system was still hazy. The entire system was checked for proper installation of filter/separator elements and everything was found to be installed correctly. One of the filter/separator elements was removed from the system and placed in a Plexiglas housing for observation. It was determined that this element could not clear the water haze from the fuel. A new element was installed in the Plexiglas housing and it was only able to run 3 minutes before it was unable to remove the water haze from the fuel.

Laboratory investigations were undertaken to determine the cause of this behavior and it was eventually determined that

- 1) The P39 additive itself was being injected at the correct concentration
- 2) Fuel conductivity, which can impact filtration performance, was well within range according to the MIL-DTL-83133 specification
- 3) The test and cleanup filter/separator elements had been installed properly
- 4) The most likely source of the problem was the P39 additive itself.

The results of these investigations were reviewed with the Air Force and DESC and a joint decision was made to discontinue evaluation of additive P39 with the possibility to re-initiate testing later in the program if budget and schedule would allow.

### **3.2.3 Individual Additive Evaluations – Additive P44**

This additive was unique in that it was the only additive tested that failed all the requirements of EI 1581 in all of the element configurations used in this program. During further testing, it was determined that the carrier portion of this additive was being attracted to the aqueous phase during SET testing which diminished in a different proportion than the active portion. Based on this unusual result, the Navy initiated further testing using their own Naval Coalescence Test (NCT). This additive was unable to pass this test. The Navy evaluators determined, based on the testing and investigations of these unexpected results that:

- 1) The P44 additive performed no worse in lab-scale testing regarding water separation capabilities than the currently approved thermal stability additive
- 2) The baseline Jet A fuel was not the cause for any of the failures since it met all specification properties
- 3) P44 showed poor coalescence properties by failing in all 5 filter types as well as the NCT coalescence evaluation
- 4) The P44 additive's bulk and carrier phases will separate when mixed with water.

### **3.2.4 Combined Additive Evaluations**

Based on the performance of the individual additives and the issues presented by additives P39 and P44, these latter two additives were dropped from consideration when preparing the 'soup' of additives to be used in the combined additive evaluation portion of this program.

The 'soup' therefore consisted of equal amounts of additives P41, P47 and P50. To prepare the soup, 5 gallons of the JP-8 fuel were added to a clean epoxy-lined 55-gallon drum. One of the candidate additives was added at a volume equal to 83.55 mg/L in the entire 18,000 gallons of test fuel. This blend was mixed. After 45 minutes of mixing, another additive was added at 83.55 mg/L for the entire 18,000 gallons of test fuel into that same 5 gallons of JP-8 and mixed. After 45 minutes of mixing the last remaining additive was added to the drum at 83.55 mg/L for the entire 18,000 gallons of test fuel. This soup blend was used to additize the 18,000 gallons of test fuel.



The soup of additives passed API/EI 1581 in the 5M420 SLV and 5M100 420 SLV filter elements and failed all others.

### 3.2.5 Conclusion

Table 1 shows the Pass/Fail results in accordance with EI 1581 for each fuel/additive combination evaluated. A “pass” rating indicates that the fuel/additive passed the EI 1581 SET criteria where a “fail” rating indicates that the fuel/additive did not pass the criteria. N/A indicates that testing was not accomplished for the designated fuel/additive combination. This was typically due to time and budget constraints for the program.

The conclusions from the testing in this program are as follows:

- 1) The P47 and P50 additives performed as well as or better than the currently approved additive, P41
- 2) The P39 and P44 additives performed more poorly than the currently approved additive, P41. More information regarding the performance of these two additives is documented in summary in paragraphs 3.2.2 and 3.2.3.

<b>Table 1 – Thermal Stability Additive Filtration Testing Results IAW EI 1581 SET</b>					
<b>Additive/Filter</b>	<b>5M 420 SBS</b>	<b>5M 420 SLV</b>	<b>5M100 420 SLV</b>	<b>5M 620 SBS</b>	<b>5M100 620 SBS</b>
Jet A Only	PASS	N/A	N/A	PASS	N/A
JP-8 Only	PASS	PASS	N/A	PASS	N/A
JP-8/P39	N/A	N/A	N/A	N/A	N/A
JP-8/P41	FAIL	FAIL	FAIL	FAIL	PASS
JP-8/P44	FAIL	FAIL	FAIL	FAIL	FAIL
JP-8/P47	FAIL	PASS	FAIL	FAIL	PASS
JP-8/P50	PASS	FAIL	N/A	FAIL	PASS
JP-8/Soup (P41/P47/P50)	FAIL	PASS	PASS	FAIL	FAIL

### 3.3 Faudi Filtration Study (BASF)

As has been discussed in Section 1.1, the BASF candidate additive was a late-comer to the program. In the process of gathering data to substantiate their request for entry into Phase II of the overall Next Generation +100 program, BASF initiated an internal program to have their P50 candidate additive evaluated for filter/coalescer performance. This testing was accomplished by Faudi Aviation GmbH in a

single element test vessel (FW10-HM-1/362-10) containing a single Model No. MIL-4-362/5 filter/coalescer and a single Model No. 60.633-120/DM separator in a horizontal, side-by-side configuration<sup>10</sup>. API/EI 1581 5<sup>th</sup> Edition "Specification and Qualification Procedures for Aviation Jet Fuel Filter/Separators" was the protocol used for the evaluation. A specification grade Jet A-1 was used containing FSII, CI/LI and SDA along with the P50 thermal stability additive at a concentration of 256 mg/L.

The test resulted in the P50 additive passing the test protocol in all criteria.

### **3.4 SwRI SAE Filter Rig**

Based on the interim data received by the Air Force during the execution of the Navy filtration testing, especially in light of the unexpected results for additives P39 and P44, the Air Force program managers thought it would be reasonable to engage other non-specification testing in an attempt to understand the unexpected behaviors of P39 and P44 in the Navy test and to perhaps understand more about the filter/separator performance of these two additives.

To that end, all of the candidate additives were submitted to SwRI for evaluation in a program that was already established to test the filter/separator performance of fuels derived from alternate sources. The following is lifted verbatim from that SwRI Project No. 08-14406 Final Report<sup>11</sup> and presented here for whatever value it brings in helping to understand the filter/separator performance of these candidate additives

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"Per ASTM D4054 (Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives), the candidate fuels should have no impact on coalescer filtration relative to a typical Jet A. The standard method for evaluating filtration performance for aviation use is API/EI 1581 5<sup>th</sup> Edition. A single element test (SET) is performed to evaluate the water and dirt removal characteristics, which includes a water challenge at 100-ppm for 30 minutes, a dirt challenge for 75 minutes, a 100-ppm water challenge for an additional 150 minutes, followed by a 3% water challenge. The test equipment is well defined in this standard but a test typically requires the use of approximately 12,000 gallons of test fuel. Testing on this scale requires a large facility and therefore limits its widespread application. For our discussions, the main component of interest is the 2,950-rpm centrifugal pump. During the water challenge, water is injected upstream of this pump so that it generates a consistent emulsion.

The challenge is how to determine the water removal characteristics given limited quantities of test fuel. A test method utilized by the automotive industry is Society of Automotive Engineers (SAE) J1488 (Emulsified Water/Fuel Separation Test Procedure). This test method utilizes a 3,500-rpm centrifugal pump to generate a fuel/water emulsion to challenge the test filter. The water challenge is 2,500-ppm of water for 150 minutes. Since the pumps were similar, the SAE J1488 method seemed like a reasonable alternative to determine if any of the candidate aviation fuels exhibited water removal issues. It is not recommended as a substitute but rather as a screening tool when fuel volumes are limited.

Since most automotive fuel filters utilize hydrophobic barrier filtration (due to cost constraints), the next challenge was to find an automotive fuel/water separator similar to what is utilized in the API/EI

1581 test method. The solution was found in the filtration system used on the U.S. Army M1A1 battle tank. Since the tank utilizes a turbine engine, the original filtration design was similar to that used for the aviation industry. The housing utilizes two coalescers and one separator in the housing. The flow patterns are similar in that the flow is inside-out for both the API/EI 1581 coalescers and M1A1 filters and the flow is outside-in for the separators. Both coalescer technologies use glass to generate larger water droplets and Teflon separator screens to repel any water that gravity does not remove.

Since the two methodologies have enough similarities, the SAE J1488 emulsified water removal test may serve as a good screening methodology for alternative aviation fuels when there are limited quantities of test fuel.

Seven samples of JP-8+100 and one sample of JP-8 ..... were received for fuel/water separation testing by SAE J1488. The JP-8+100 samples contained various types of +100 additive at a treat rate of 256-mg/L. Where several +100 additives are indicated, equal parts of each were added for a combined total of 256-mg/L.

Overall, the time-weighted average water removal efficiency (TWA WRE) was 100% for all samples. This suggests that these combinations of +100 additives should not interfere with the sample's ability to separate water when used with a typical filter/separator designed for aviation fuel."

### **3.5 ICE Rig Testing (AFRL)**

Beginning in March 2007, the four +100 candidates and the original GEBetz additive were evaluated in the Infineum Coalescence & Emulsion (ICE) rig at AFRL<sup>12</sup>. All additives were run through the standard test procedure and the data was collected and compared to the baseline +100 additive as well as 'neat' (unadditized) JP-8.

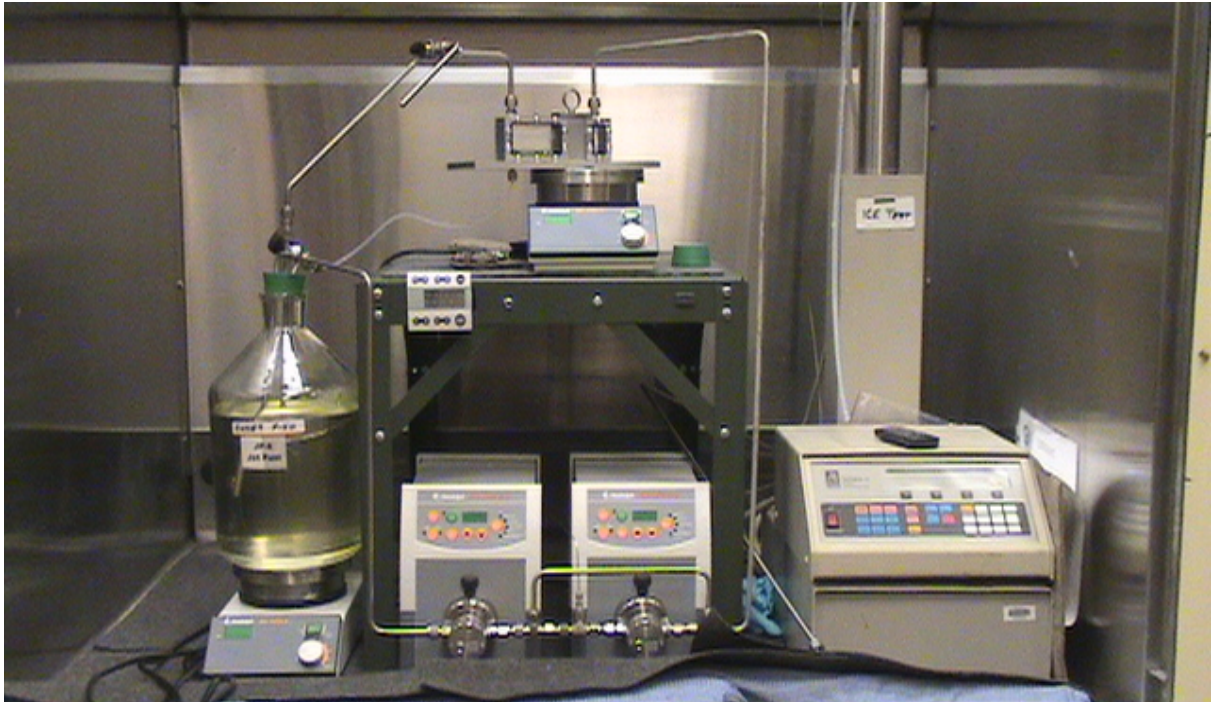
There were two goals for this program. First and foremost, to evaluate and assess the impact of the primary Next Generation +100 candidate additives on the general performance of typical filter/coalescer systems in use by the United States Military. The secondary goal was to evaluate the applicability of this bench-scale filter/coalescer test to evaluating and assessing water separation characteristics of fuels. It was not the intent of this program to replace API/EI testing protocols but to provide researchers with a bench-scale test that took minimal time and minimal fuel and could be used to 'rank' fuels with respect to their water separation characteristics.

#### **3.5.1 Description**

Over the years, many attempts had been made, with varying degrees of success, to develop a small scale test that could be used as a reliable screening tool. One such test method was developed by Infineum Co. (UK). It was developed based on earlier works in the field and was built specifically to evaluate the impact of Infineum's own additive candidate in the Next Generation +100 Additive development program. Since the Air Force Research Laboratory at Wright-Patterson AFB, OH was performing and/or managing the testing for this Next Generation +100 program, Infineum generously provided duplicate key components of their system to AFRL for use in the program so that all candidate additives could be equally ranked with respect to their impact on filter/coalescer systems using one evaluation system and set of criteria. The apparatus, dubbed the 'ICE' (Infineum Coalescence & Emulsion) rig (Figure 3), was

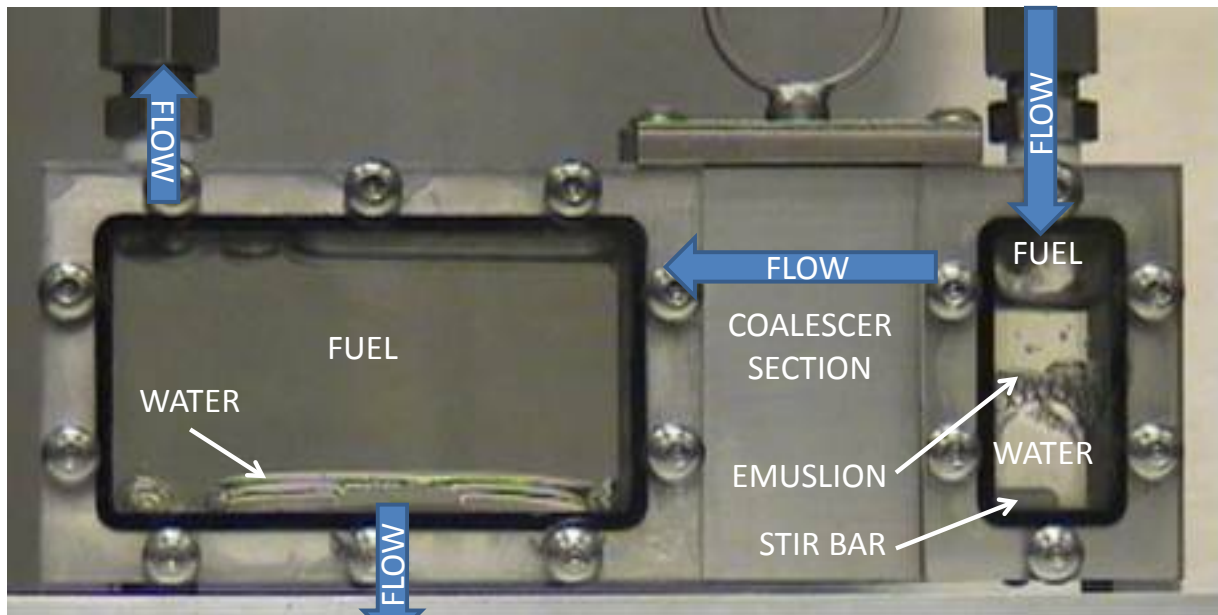
assembled in 2007 by the University of Dayton Research Institute (UDRI) with assistance from Infineum. The filter test chamber was designed and fabricated Infineum and provided to the Air Force for use in this program. The design of this system was based around using small pieces of actual filter/coalescer material to evaluate the impact of the additives on that material over a relatively short period of time, while being able to observe the fluid behavior through several clear viewing windows.

The ICE rig consists of a 5 liter glass fuel storage container mounted on the left side of the rig supported by a magnetic stirrer, which is operated continuously during experimentation. Neat or additized fuel is pumped from this container through a gear pump, which begins to agitate the fuel, at a rate of 100 ml/min. The agitated fuel is then contaminated with reverse osmosis treated water at a rate of 4.5ml/hr. via a 1/16 stainless steel tube drip. The wet fuel is then pumped through a second gear head pump, set to operate at about 2,000 rpm, to homogenize the fuel and water mixture. After the homogenization pump, the fuel passes through a pressure transducer and into the filter test chamber.



**Figure 3 - ICE Test Rig**

The filter test chamber (Figure 4) consists of a welded aluminum chamber divided into three chambers - two viewing ports and one filter case. Overall, the filter test chamber is about 5.5 inches in length, 2 inches tall and 1 inch wide. The fluid entry port is on the extreme right when facing the rig and is 1.5cm wide by 3.5 cm high, and contains a tiny magnetic stir bar to help agitate the fluid even more. From here the fluid flows through the two stages of filter/coalescer test specimen, which is cut to be slightly over one inch square. By cutting the filter pieces slightly larger than the one inch square hole, a good tight fit is ensured in the test apparatus so that all fuel passes THROUGH the filter and not



**Figure 4 - ICE Rig Filter Element Test Chamber**

AROUND it. The last port on the filter test chamber (extreme left) is 6.5 cm wide by 3.5 cm high. Both this port and the initial entry port are enclosed by safety plastic, sealed with Viton O-rings and several bolts.

The fuel/water emulsion created by the two pumps flows into the right chamber where a magnetic stirrer maintains the emulsion. This emulsion flows through the filter section where the filter separates the emulsion into a water phase and a fuel phase. Once the water and fuel have been separated by the filter section, both phases collect in the chamber on the left side where the two phases are allowed to acquiesce. The water is drained from the bottom of the cell through a control hand valve and into the original fuel supply reservoir. A separate needle valve in that line allows for fuel samples to be drawn and tested prior to re-contamination in the original fuel jug. Water is never removed from the system during the test. Fuel samples taken from the valve are analyzed by Karl Fischer to measure dissolved water contamination levels. The fuel is pumped off the filter test chamber top and also flows into the original fuel supply reservoir. A magnetic stirrer maintains some limited liquid turbulence to minimize any natural separation of water from the fuel. This test demonstrates how well the filter/coalescer test section separated water from the fuel.

A normal test is conducted over a period of 72 hours, with photographic documentation at the start of the test and then at 1, 5, 24, 48, and 72 hours into the test. After the experiment, any fuel and water remaining in the test section are drained back into the original jug and allowed to settle for five additional hours. This aspect of the experiment demonstrates the behavior of the fuel additives that may have been mixed with the fuel sample prior to the start of the experiment. Since the filter/coalescers in field service typically see several thousands of gallons of fuel, the continuous flow of emulsified fuel/water passing through the test filter repeatedly is representative of the USAF's larger filter/coalescer systems.

For these tests, a section of a typical API/IP 5<sup>th</sup> Edition filter (non-M100) was used to provide the filter/coalescer pad used in the filter/coalescer test chamber.

### **3.5.2 ICE Rig Testing Conclusions**

Based on the results of photographic qualitative evidence and dissolved water measurements, Additive P50 performed the best with regard to water separation and filter/coalescer performance impact, being virtually the same as the unadditized fuel. This additive would be the first choice for use if the choice was based solely on water separation and filter/coalescer performance characteristics. Additives P47 and P41 performed acceptably with respect to water separation and filter/coalescer performance. Both of these additives initially exhibit no negative impact on filter/coalescer performance but after a short period of exposure to these additives, filter/coalescer performance degrades.

Additives P44, P39 and the Additive Soup exhibit substantial negative impact on both water separation and filter/coalescer performance with P39 ranking the worst as it almost immediately disables the filter/coalescer. P44 and the Soup fair only slightly better.

*It is worthy to note that even though this ICE rig testing and the Navy filtration testing (Section 3.2) were performed years apart (with the ICE testing being accomplished before the Navy program), the ranking of additive performance determined from each program was exactly the same. Both ICE rig*

*testing and the Navy API/IP 1581 testing predicted the same filter/water separation performance. This indicates that the ICE rig may indeed be a very useful tool in future fuel/additive evaluation programs when looking at the impact on filtration and water separation characteristics.*

In conclusion, only additives P50, P47 and P41 exhibit either no or minimal negative impact on water separation and filter/coalescer performance and these additives are the most likely to be able to function in the field with minimal negative impact. However, additives P44 and P39 would likely cause filter/coalescer issues in the field with P39 being the most likely to cause the most significant negative issues.

### **3.6 Emissions Evaluations (Canada)**

The Royal Military College of Canada (RMCC) conducted at least two studies<sup>13,14</sup> evaluating the impact of thermal stability additives for military jet fuel (JP-8, NATO Code F-34 and Jet A-1, NATO Code F-35). The test rig used was an atmospheric pressure sector rig designed around a T56 engine combustion chamber. Comparisons of nozzle deposition and emissions were conducted. In the initial tests (2008) using JP-8 (F-34), additives tested were limited to the currently approved GEBetz Spec-Aid 8Q462 additive as well as the Next Generation candidate additives P39, P41, F44 and P47 and were conducted using JP-8 (NATO Code F-34). Additive P50 had not completed initial US Air Force evaluations at the time of the RMCC studies so it was not included initially. However, P50 was included in a subsequent 2009 study which was conducted using Jet A-1 (NATO Code F-35).

In the Emissions and Deposition study, each additive was blended in the test fuel at a concentration of 256 ppm. Prior to each test, the combustion chamber liner and associated hardware were cleaned and weighed. During the 10-hour test, gaseous emissions as well as smoke and exhaust gas temperatures were measured. After the test the rig was disassembled components were photographed and weighed. The fuel nozzle was also checked for fouling using Phase Doppler Anemometry and laser optical pattern techniques.

RMCC also conducted Deposition Reduction studies. In these tests, the rig was prepared by cleaning the combustion section and related components as in the Deposition Study. The rig was operated for three hours with the baseline fuel. The rig was disassembled and the parts were photographed and weighed to determine the amount of deposition. Without cleaning the parts, the rig was reassembled and operated for an additional 3 hours with the baseline fuel containing the additive being evaluated.

#### **3.6.1 Conclusions**

While the detailed conclusions are presented in the reports produced by RMCC for these programs, they can be summarized as follows

- Emission and smoke production showed that the differences observed between the baseline and additive fuels were minimal indicating neither negative nor positive impact on these characteristics. For the exhaust emissions measured:
  - additive P41 caused slightly higher hydrocarbon(HC) and carbon monoxide (CO) emissions than the other additives and the baseline F-34 fuel in the order of 10% - 16%.

- The P44 additive produced lower HC emissions when compared to straight F-34 baseline fuel in the order of about 14%.
- Similar levels of sooting in the combustion section were observed for all fuel formulations
- No evidence of deposit cleaning abilities were observed for any of the additives

The report concludes generally that “No detrimental performance with respect to emissions, smoke and soot production and nozzle fouling was observed with the prototype additives.” It also mentions that the conditions for the program were very “conducive” to the formation of deposits which might have impacted the test results that showed no deposition reduction.



## 4.0 Conclusions and Recommendations

Four new additives along with the currently approved and in-use +100 additive were evaluated in this program to qualify them for use in aviation systems. Testing on these additives in this program consisted of

1. Specification in accordance with MIL-DTL-83133
2. Fit-For-Purpose testing including
  - a. Jet Fuel Thermal Oxidation Tester (JFTOT)
  - b. Additive-Additive Compatibility Testing
  - c. Lubricity Testing
  - d. Electrical Conductivity Long-term Stability
  - e. Fuel System Icing Inhibitor Testing
  - f. Storage Stability Testing
3. Materials Compatibility
4. Fuel Gauging Studies
5. Engine Component Testing including
  - a. Engine Fuel Inlet Filtration Testing
  - b. Cold Fuel Atomizer Bench Testing
  - c. APU Ground and Altitude Starting
  - d. APU Endurance Testing
6. Hot Gas Path Materials Testing
7. Fuel Nozzle Testing
8. Combustor Rig Testing including
  - a. Altitude Ignition Testing
  - b. Full Annular Testing
9. Fuel Filtration/Water Separation Testing
  - a. Navy API/IP 1581 testing
  - b. Faudi Filtration Study (P50 additive only)
  - c. SwRI SAE Filter Rig testing
  - d. AFRL Infineum Coalescence and Emulsion Testing
10. Emission Evaluations

Based on this overall testing, **all additives have been approved** for use in military turbine engines by the engine OEMs (see the appendix). However, based on the performance of these additives on an individual basis, **AFRL recommends** the following additives for procurement and fielding (Table 2) (in no particular order). Additives not receiving AFRL's recommendation for procurement and fielding were non-recommended mainly due to anomalous or nebulous data relating to filtration and water separation. It is recommended that these additives undergo additional filtration/water separation testing and that the results of the testing in this program be combined with any new data to re-evaluate AFRL's position regarding recommendations for procurement and fielding.

**Table 2 – Recommended Additives**

<b><i>Final Recommended Additives for Procurement and Fielding</i></b>			
<b>Additive P-Code</b>	<b>POSF Designator</b>	<b>Manufacturer</b>	<b>Manufacture Trade Name or Code</b>
P41	POSF-4160/4580	GE Betz	<b>Spec-Aid 8Q462</b> (Currently approved add.)
P47	POSF-4753	Infineum/ExxonMobil	<b>AV100</b> (NB-31011-33)
P50	POSF-5090	BASF	<b>Kerojet™ 100</b> (Kerocom 69781)

# **APPENDIX**

## **OEM Approval Letters**



**Pratt & Whitney**  
A United Technologies Company

To: Fuels and Energy Branch  
AFRL/RZPF  
Attn: M. Lawson, R. Morris, T. Edwards  
1790 Loop Rd. N.  
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Pamela Serino  
Director, Quality Tech Support Office  
Defense Logistics Agency Energy Q  
8725 John Kingman Rd, Suite 2843  
Fort Belvoir, VA 22060

From: Gary Roberge, Chief Engineer Operational Military Engines  
Tedd Biddle, P&W Fuels Fellow

Subject: Pratt & Whitney Approval of Four JP-8+100 Additives for Use in P&W Military Engines


Date: 01 June 2011


The following four thermal stability improving additives are approved as JP-8+100 additives for use in all Pratt & Whitney (P&W) military engines: BASF Kerojet®100, Nalco EC5100A PLUS, Infineum NB 31011-33, and Lubrizol OS 169558F. Each additive is approved for use at a maximum allowable concentration of 256 milligrams per liter (mg/L) blended into jet fuel.

In a program funded by the U.S. Air Force, P&W led an engine and airplane Original Equipment Manufacturer (OEM) team in evaluation of the above four additives. The test program was performed in accordance with ASTM D4054 "Guideline for the Qualification and Approval of New Fuels and Additives. The technical approach for qualifying the candidate additives was agreed upon by the Air Force Research Laboratory, (AFRL), the Defense Energy Support Center (DESC), the engine manufacturers and Boeing. P&W, General Electric Aviation (GE), Rolls Royce (RR) and Honeywell Aerospace acted as a team in designing tests, reviewing data, interpreting the results, and writing the final report.

The work performed by P&W, GE, Honeywell, RR, AFRL, Southwest Research Institute (SWRI), the University of Dayton Research Institute (UDRI), and the U.S. Navy compared the currently approved GE-Betz Spec-Aid 8Q462 to that of the four candidates in two baseline fuels. Testing included impact on Mil-DTL-83133, Grade JP-8, specification properties; fit-for-purpose properties; compatibility with fuel-wetted metals and nonmetallic materials; altitude relight tests, full annular emission tests, fuel nozzle tests, tests to determine compatibility of the combusted products on hot gas path materials, APU tests, and an engine test.

The results of the testing performed under this program showed the additives to have no negative impact on engine or airplane safety, performance, or durability. The work conducted under this program supports the position that all four of the candidate additives are fit for purpose for use in commercial and military engines as fuel thermal stability improvers.

  
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Tedd Biddle  
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Cc: Thomas G. Johnson, F135; William Hastings, F119; David McDermott, F100; Mark Von Nieda, F117;  
Jon Haefner, Validation Manager



## GE Aviation

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Leader, Alternative Fuels  
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[Mike.Epstein@GE.com](mailto:Mike.Epstein@GE.com) 513-243-5918

To: USAF Fuels and Energy Branch  
AFRL/RZPF  
Attn: M. Lawson, R. Morris, T. Edwards  
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Ms. Pamela Serino  
Director, Quality Tech Support Office  
Defense Logistics Agency Energy Q  
8725 John Kingman Road, Suite 2843  
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Mr. Carl-Bosch-Str. 38  
BASF  
Building J550, Room B1029  
DE 67056 Ludwigshafen Germany

From: Mr. Mike Epstein, Leader Alternative Fuels  
Mr. Tom Maxwell, General Manager, Military Engineering  
Mr. Donald L. Gardner, GE Aviation Chief Engineer's Office

Subject: GE Aviation Approval of JP-8+100 Candidate Additive for use in GE Military Engines.

Date: 23 February, 2012

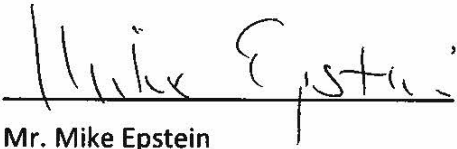
The following three thermal stability improving additives were approved as JP-8+100 additives for use in all GE Aviation (GE) military and CFMI military engines in a letter submitted 28 September 2011:

Infineum NB 31011-33  
Lubrizol OS 169558F  
Nalco EC5100A (formerly labeled VX7603)

The BASF candidate additive, Kerojet™ 100 was not approved in a separate letter on the same date, because the data submitted demonstrated higher risk for engine safety, performance or durability. Since that date, further communication with AFRL and with program lead Pratt & Whitney has resulted in additional information and product testing which mitigated the concerns for this additive product.

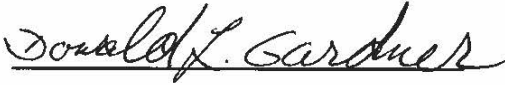
As a result of this further review of testing and analysis, the BASF Kerojet™ 100 additive is approved for use in GE and CFMI military engines.

Each additive is approved for use blended into the fuel at a maximum allowable concentration of 256 parts per million (ppm) per unit of fuel, by volume. The work conducted under this program supports the position that the four approved additives are fit for purpose for use in commercial and military engines as fuel thermal stability improvers.

Handwritten signature of Mike Epstein in cursive script, underlined.

Mr. Mike Epstein

Leader, Alternative Fuels

Handwritten signature of Donald L. Gardner in cursive script, underlined.

Mr. Donald L. Gardner

Chief Engineer's Office

Handwritten signature of Tom Maxwell in cursive script, dated 2/24/12, underlined.

Mr. Tom Maxwell

General Manager, Military Engineering

Engineering & Technology  
Honeywell  
111 S. 34<sup>th</sup> Street  
Phoenix, AZ 85034

To: Fuels and Energy Branch  
AFRL/RZPF  
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Ms. Pamela Serino  
Director, Quality Technical Support Office  
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8725 John Kingman Rd, Suite 2843  
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From: Jim Kroege, Director Propulsion Engineering  
George Beardsley, Director APU Engineering  
Randy Williams, Engineering Fellow, Combustion & Fuels

Subject: Honeywell Approval of New Thermal Stability Improver Fuel Additives (+100 Additives)

Date: 14 October, 2011

This letter formally documents Honeywell approval of four new thermal stability improver additives (+100 additives) for use in all Honeywell military engines and APUs at concentrations up to 256 mg/L. The new +100 additives include Lubrizol OS 169558F, Infineum NB 31011-33, Nalco EC5100A PLUS, and BASF Kerojet™ 100.

The Fuels and Energy Branch of AFRL (Air Force Research Laboratory) teamed with a number of additive manufacturers to develop alternative +100 additives that had thermal stability improvement as good as or better than the current approved additive. Honeywell was part of an industry team that subsequently evaluated four new thermal stability improver additives as part of the USAF Evaluation of Next Generation High Heat Sink Fuel Additives program. The AFRL enlisted Pratt & Whitney (P&W) to lead the project, with other aircraft and engine OEMs sub-contracted to P&W. The objective of the program was to determine the suitability of four candidate fuel additives for use in military aircraft and engines. The new +100 additives were developed to provide competition for the current sole source +100 additive allowed in JP-8 military jet fuel. During testing and evaluation, all the additives were coded so the test laboratories and OEMs (original equipment manufacturers) did not know the manufacture of the additives.

The current +100 additive is manufactured by GE Water and Process Technology, and is marketed under several trade names including Spec-Aid 8Q462, FS100C, and APA101. Spec-Aid 8Q462 is the military version of the additive, and is authorized for use in JP-8+100 fuel (NATO Code F-37) per MIL-DTL-83133. FS100C and APA101 (Shell Aviation) are

Page | 1



commercial versions of the same additive. The maximum concentration for use of the Spec-Aid 8Q462, FS100C, and APA101 additives is 256 mg/L. The Spec-Aid 8Q462 additive is approved for all Honeywell military APUs and propulsion engines. All three additives are approved for most Honeywell commercial APUs and engines.

An extensive test evaluation was completed on the new +100 additives following ASTM D4054 "Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives". Test results summarized in the program final report (Ref. 1) showed no adverse impact of any new +100 additive on engine or APU performance, operability or durability. Following normal practice, specification and fit-for-purpose (SwRI and Goodrich) tests were completed at four times the normal use concentration of 256 mg/L (or 1024 mg/L) on each additive individually. Material compatibility tests with fuel wetted metals and non-metallic materials (UDRI), compatibility tests with hot gas path materials (P&W), and ground filtration tests (U.S. Navy) were also completed on each additive at 1024 mg/L concentration. Fuel nozzle coking tests (SwRI) were completed on each additive at 250 mg/L and a soup of all additives each at 250 mg/L concentration (1250 mg/L). Component, rig, and engine tests were conducted with a soup of all five additives (current additive and four candidate new additives) each at 1x normal use concentration or 1280 mg/L total additive concentration. Testing included combustor altitude relight test (Rolls-Royce), engine inlet filtration test (SwRI), atomizer cold spray test (Honeywell), APU cold and altitude start test (Honeywell), combustor rig performance and emissions test (P&W), and an APU 150-hour endurance test (Honeywell).

Although Honeywell approves all four new additives for use, there were some results that may affect field implementation and warrant further review. Since the +100 additive is typically injected into the fuel when filling the aircraft refuelling trucks, many of these issues would only affect fuel that was off-loaded from an aircraft or samples taken from the refuelling truck.

- All additives except the Nalco additive had high existent gum during specification tests at 4x concentration. When retested at 1x concentration the BASF additive still was slightly over the specification limit. While this is due to the hydrocarbon carrier in the additive package, testing of JP-8+100 fuel may result in existent gum being over the specification limit if tested in the field. Note that even the current +100 additive had high existent gum when tested at 2x normal use concentrations. Extensive thermal stability and fuel nozzle coking tests showed all additives improved thermal stability and reduced deposition in fuel system components.
- All the additives have dispersants and detergents which can clean ground and aircraft fuel systems sending accumulated dirt and particulates downstream. Monitoring of ground filtration equipment and engine and APU inlet filtration after introduction of +100 additives or when changing from one additive brand to another is recommended.
- The Lubrizol additive had a distinctive yellow color which resulted in yellowing of the fuel even at 1x normal use concentration. The yellow color fuel may make fuel visual quality checks (white bucket test) more difficult, including detection of free water (haze) and particulates. The +100 additive is usually injected just prior to aircraft fueling, and downstream of ground water removal and filtration equipment.
- Extensive material compatibility tests on a wide range of metals and non-metallic materials used in aircraft and engine fuel systems were completed by UDRI (University of Dayton Research Institute). Tests were run at 4x normal use concentration, but were repeated at 1.5x normal use concentration if any possible degradation in material



properties was noted. Results were reviewed by Honeywell material and fuel system specialists who concurred with UDRI conclusions that no adverse effect due to use of any of the new additives would be expected. Increased monitoring of aircraft and engine fuel systems is recommended during introduction of any new additive, including the new +100 additives.

- The BASF additive was noted to have a higher viscosity than other +100 additives which made the additive a little more difficult to handle at room temperatures. Handling at low temperatures in the field may be more difficult with this additive than the other +100 additives.
- It is recommended that a thorough field evaluation be conducted on each new +100 additive to evaluate handling issues and any long term effects prior to fleet wide use. Extensive field evaluations were conducted on the current +100 additive prior to its introduction.

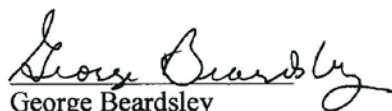
Summary – Four new thermal stability improver additives (+100 additives) are approved for use in all Honeywell military engines and APUs at concentrations up to 256 mg/L. The new +100 additives include Lubrizol OS 169558F, Infineum NB 31011-33, Nalco EC5100A PLUS, and BASF Kerojet™ 100. The new +100 additives were thoroughly evaluated, and test results indicated there would be no adverse impact of any new +100 additive on engine or APU performance, operability or durability.

#### References

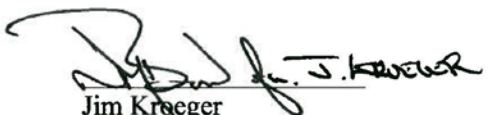
1. Evaluation of Next Generation High Heat Sink fuel Additives – Phase II – Additives Qualification, Delivery Order 0015, Report No. TBD (not yet assigned).



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Date 10/01/2012

Our ref : JP8+100 Approval

Your ref

## Rolls-Royce Approval of JP+100 Additives

Dear Sir or Madam,

**Note that the following statement is for information only and does not constitute a formal statement of approval for any engine types or additives listed below.**

Rolls-Royce controlled documentation does not allow letters or memoranda as evidence of approval. Only the formal engine documentation should be used to define fuels and fuel additives which are approved for use at any point in time. Therefore, operation of Rolls-Royce engines must always be in accordance with these formal operating instructions. Specifically, fuels and/or additives used must be in compliance with those listed in the latest version of this documentation. These documents will be updated to reflect the findings discussed below.

In a program funded by the U.S. Air Force, P&W led an engine and airplane Original Equipment Manufacturer (OEM) team in evaluation of the additives defined below. The test program was performed in accordance with ASTM D4054 "Guideline for the Qualification and Approval of New Fuels and Additives. The technical approach for qualifying the candidate additives was agreed upon by the Air Force Research Laboratory, (AFRL), the Defense Energy Support Center (DESC), the engine manufacturers and Boeing. P&W, General Electric Aviation (GE), Rolls Royce (RR) and Honeywell Aerospace acted as a team in designing tests, reviewing data, interpreting the results, and writing the final report.

The work performed by P&W, GE, Honeywell, RR, AFRL, Southwest Research Institute (SWRI), the University of Dayton Research Institute (UDRI), and the U.S. Navy compared the currently approved GE-Betz Spec-Aid 8Q462 to the four new candidates in two baseline fuels. Testing included impact on MIL-DTL-83133, Grade JP-8, specification properties; fit-for-purpose properties; compatibility with fuel-wetted metals and nonmetallic materials; altitude relight tests, full annular emission tests, fuel nozzle tests, tests to determine compatibility of the combusted products on hot gas path materials, APU tests, and a engine test.

The results of the testing performed under this program showed the additives to have no negative impact on engine safety, performance, or durability. The work conducted under this program therefore supported the position that all four of the candidate additives are fit for purpose.

Rolls-Royce plc Registered office: 65 Buckingham Gate, London SW1E 6AT.  
Company number: 1003142. Registered in England.



**Rolls-Royce**

These additives have also been assessed in compliance with Rolls-Royce Fuels Evaluation, Approval and Management of Change processes and found to be fit for purpose for use in the following engines as fuel thermal stability improvers.

The following thermal stability improving additives were assessed as potential JP-8+100 additives for use in Rolls-Royce engine types defined below:

GE-Betz Spec-Aid 8Q462, BASF Kerojet 100, Nalco VX7603, Infineum NB 31011-33, and Lubrizol OS 169558F.

Each additive will be approved for use at a maximum allowable concentration of 256 milligrams per liter (mg/L) blended into jet fuel.

These additives were evaluated and found satisfactory for use in the following engine types:

AE3007H (Global Hawk), T56 – all variants, AE 1107 (Osprey), Model 250 helicopter engine – all variants, AE 2100 (C130), BR700-710 A2-20, Pegasus – all variants, Adour – all variants.

Applicable engine documentation will therefore be updated to reflect the approval status of these additives and hence formally signify Rolls-Royce approval.

For those engines which already list JP8+100 this will remain applicable and will apply to the above additives. The JP8+100 will be added to those engine types above which do not yet list it as approved.

Note that technical data gathered and reviewed for these clearances will be used as the basis for evaluation of suitability for use in other engine types as and when required.

Rolls-Royce supports the update of MIL-DTL-83133 (JP8+100 Grade) to include the above additives at the prescribed dose rate.

On behalf of Rolls-Royce

Chris Lewis. Company Specialist – Fuels.

Copy:

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